# Delphes Studies on Angles of Acceptance

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# Overview

- A muon collider is a proposed solution to answer questions in fundamental high-energy physics reserach
- Instead of colliding stable particles such as protons or electrons, a muon collider will collide muons
- Muons are unstable, but their collisions give more insight than proton or electron collisions at similar energies

# Overview

- The current proposed design for a muon collider includes tungsten cones which absorb particles/jets with pseudorapidity $|\eta| > 2.5$
- These cones are necessary to reduce noise from beam-induced background

# Overview

- This summer, I investigated if processes of interest are compatible with the capabilities of the current working design of the muon collider
- Specifically, I sought to answer whether jets will be accepted into the detector itself or end up in the cones or beam pipe

# Overview

- One Higgs production mechanism of interest for the muon collider is vector boson fusion
- In a $\mu^+\mu^-$ collision, both muons convert to neutrinos and emit $W^\pm$ bosons, which collide and produce one or two Higgs which then decay into bottom quarks
- The energy scales proposed for the muon collider are high enough that $\sim 10\%$ of Higgs products are too forward to be read in the detectors at $3$TeV and $\sim 30\%$ of products are too forward to be read at $10$TeV

# Overview

- The following histograms show the predicted $p_T$ and $\eta$ for Higgs and bottom quarks produced at center of mass energies $\sqrt{s} = 3, 5, 10, 15$TeV
- MADGRAPH was used for simulation and Delphes was used for reconstruction
- 50,000 events were sampled for each center of mass energy
- Higgs were forced to decay into $b\bar{b}$ for each sample

# Results - Single Higgs

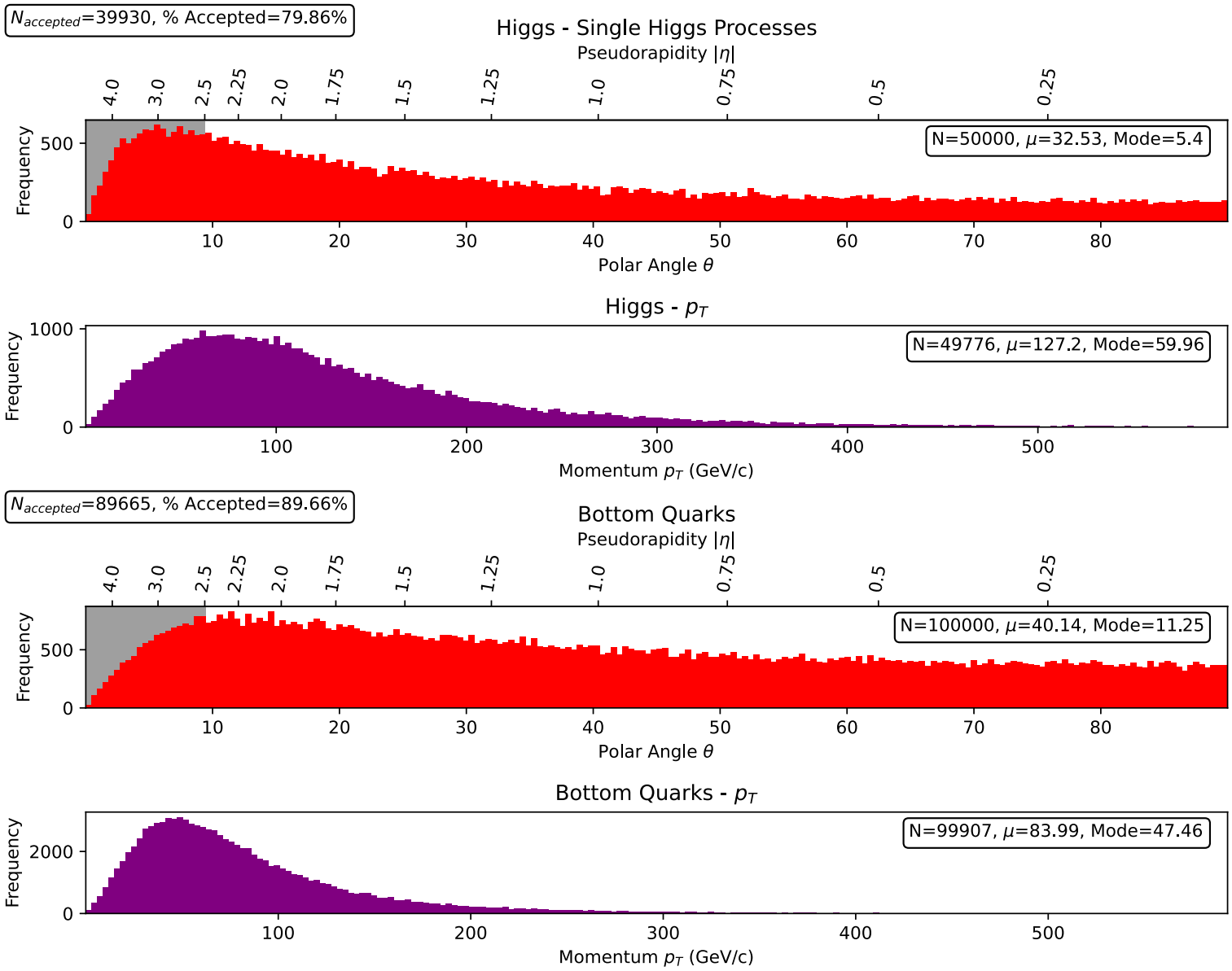


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 3\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

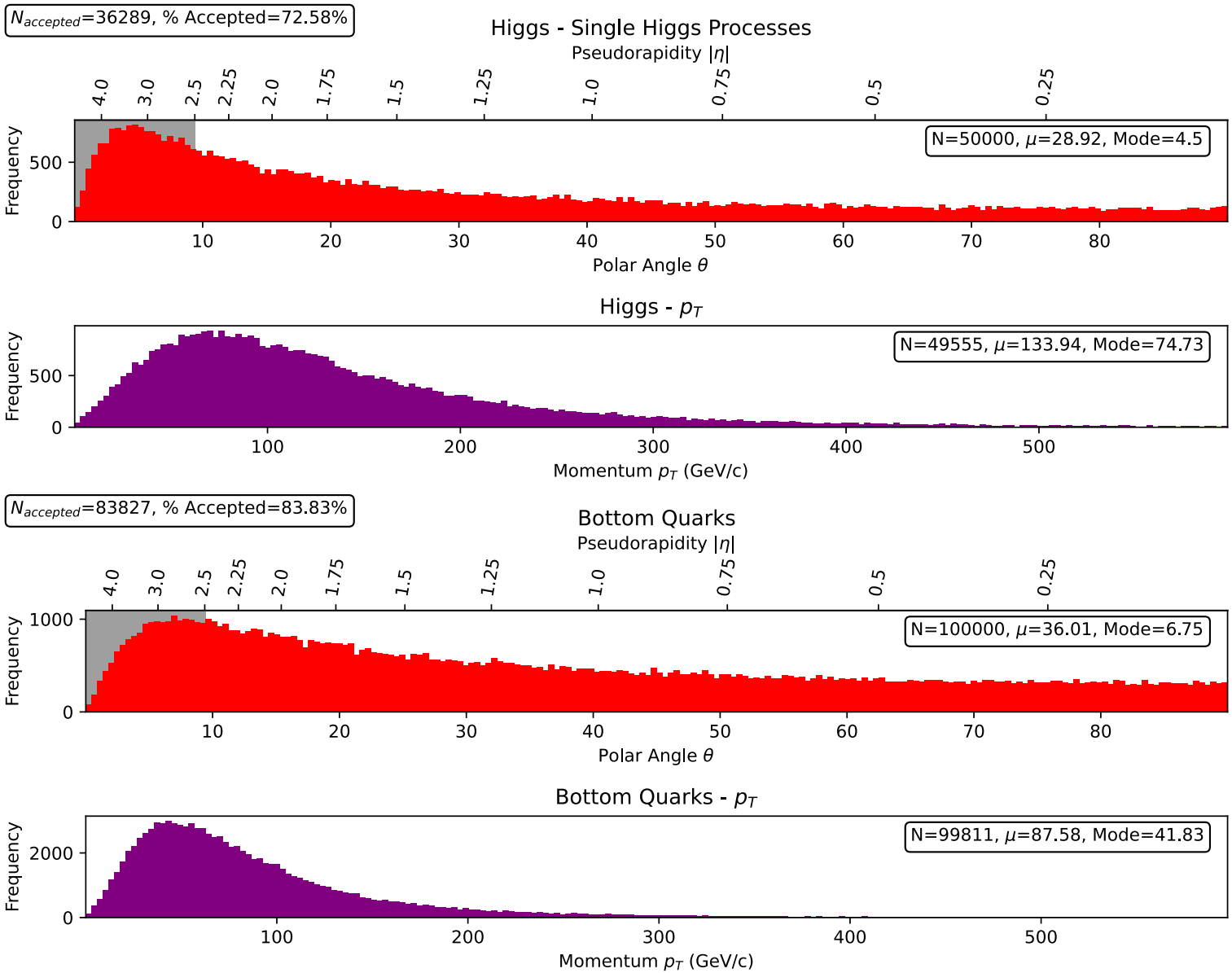


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 5\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

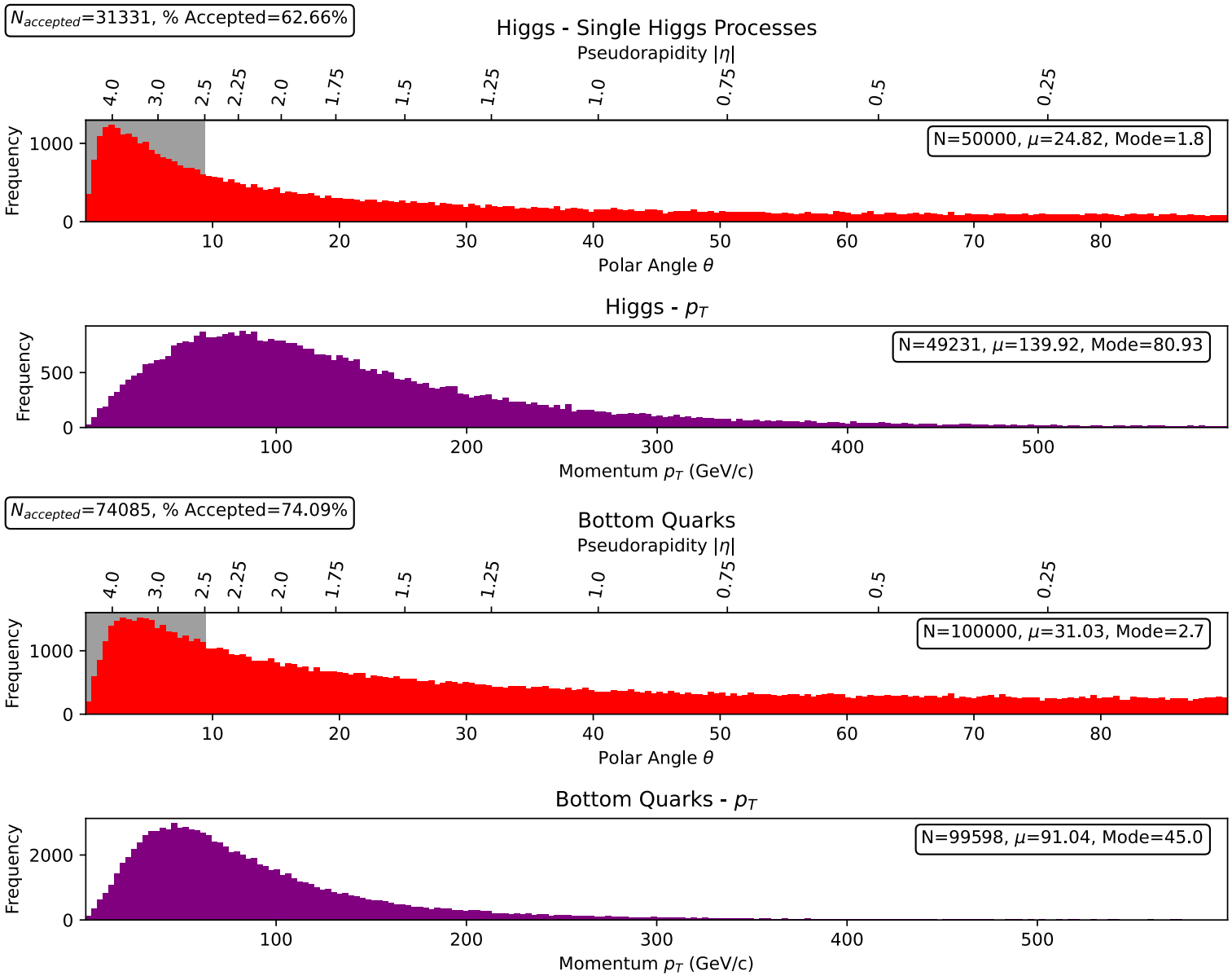


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 10\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

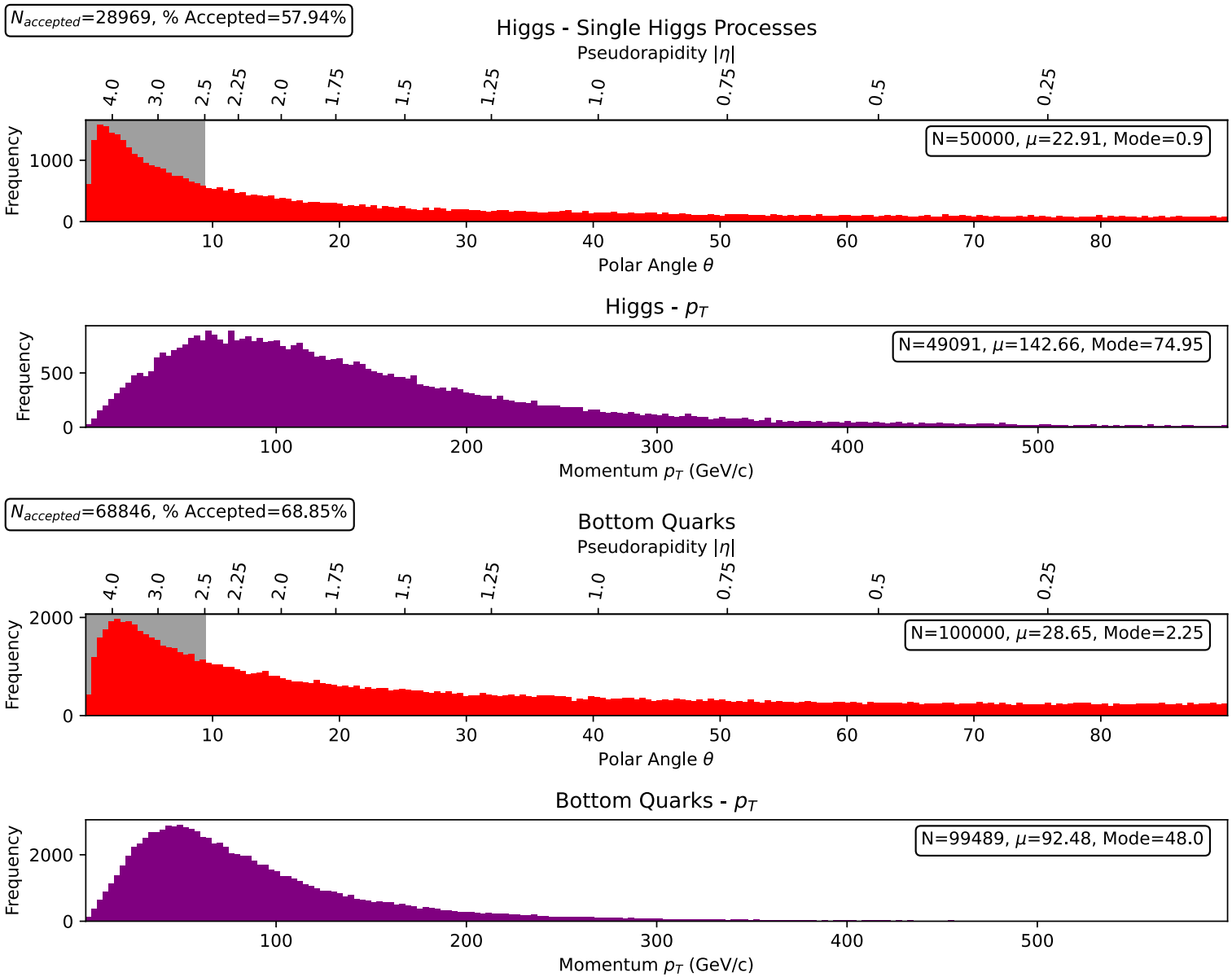


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 15\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

The following are simulated values of $\eta, \Delta\eta, \Delta\theta$ and $p_T$ for generated jets from the resultant bottom quarks

# Results - Single Higgs

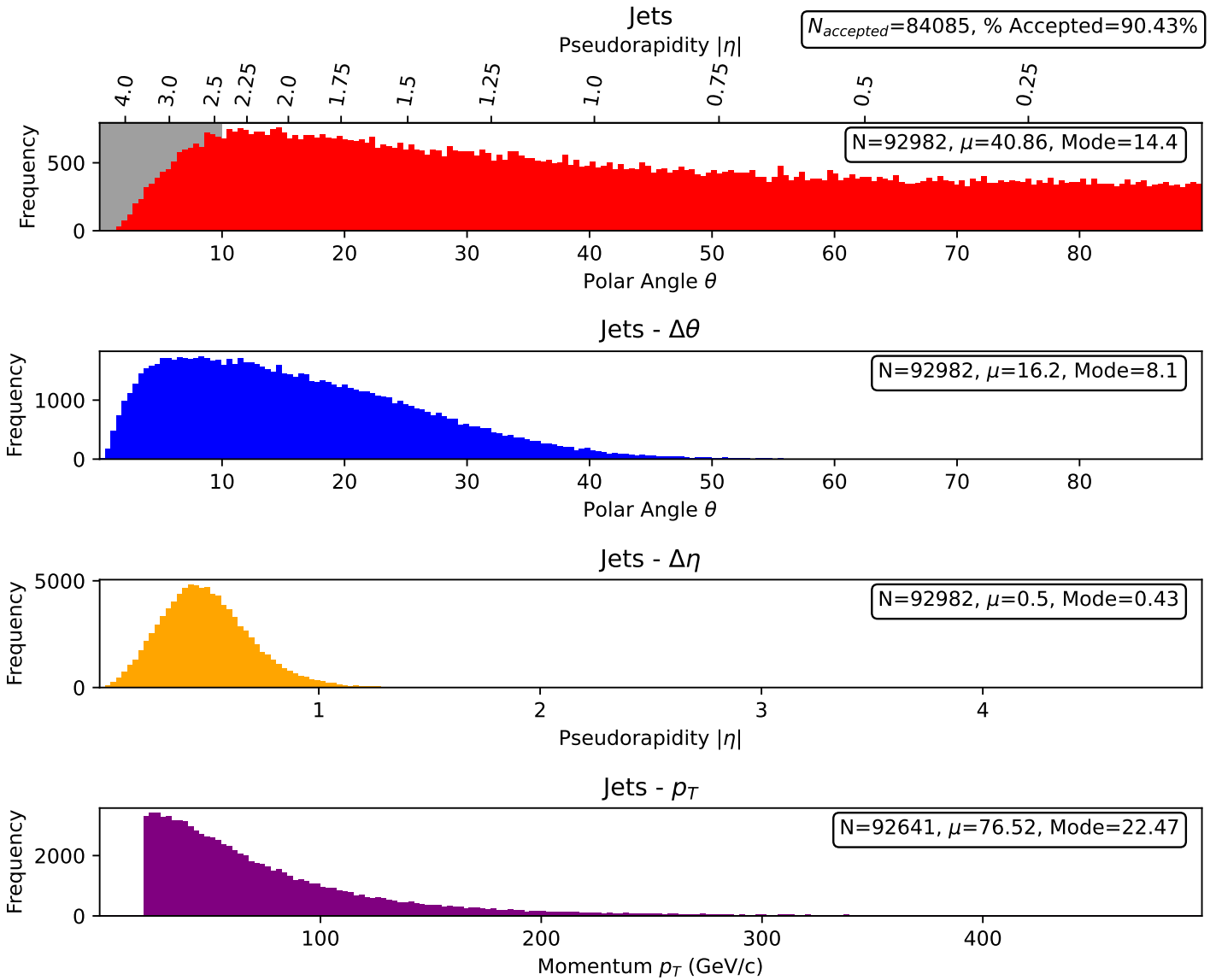


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 3\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

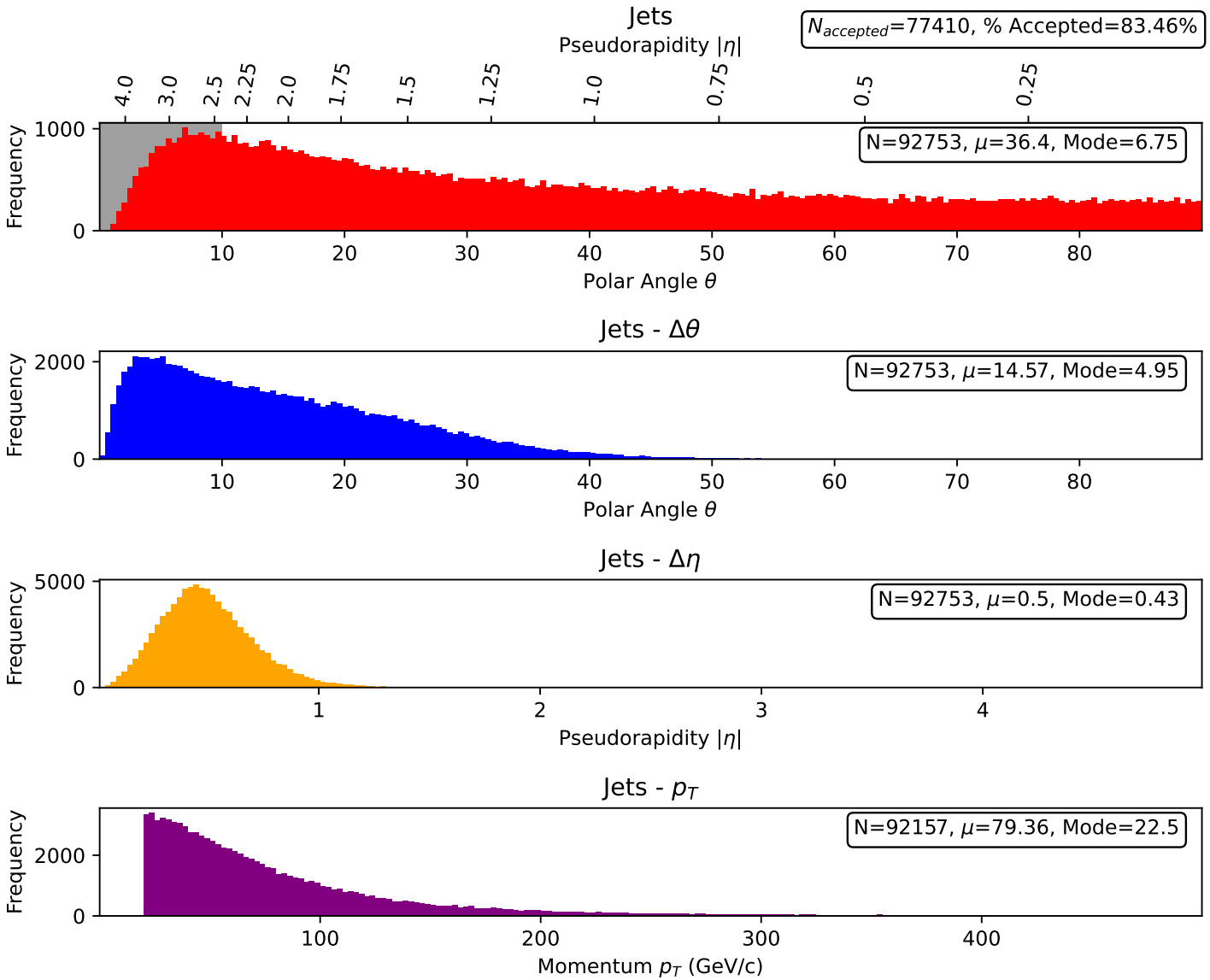


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 5\text{TeV}, N_{\text{events}} = 50,000$

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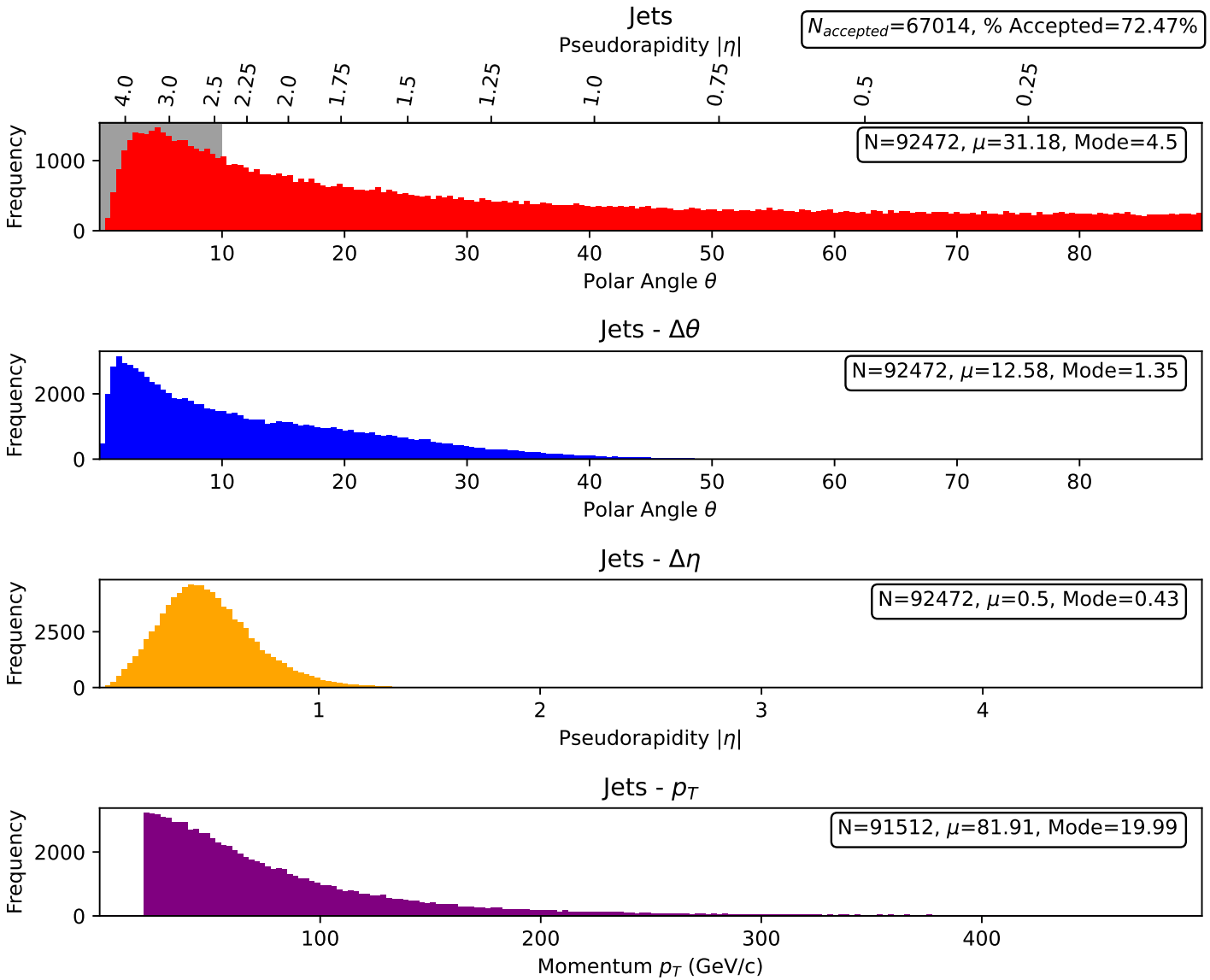


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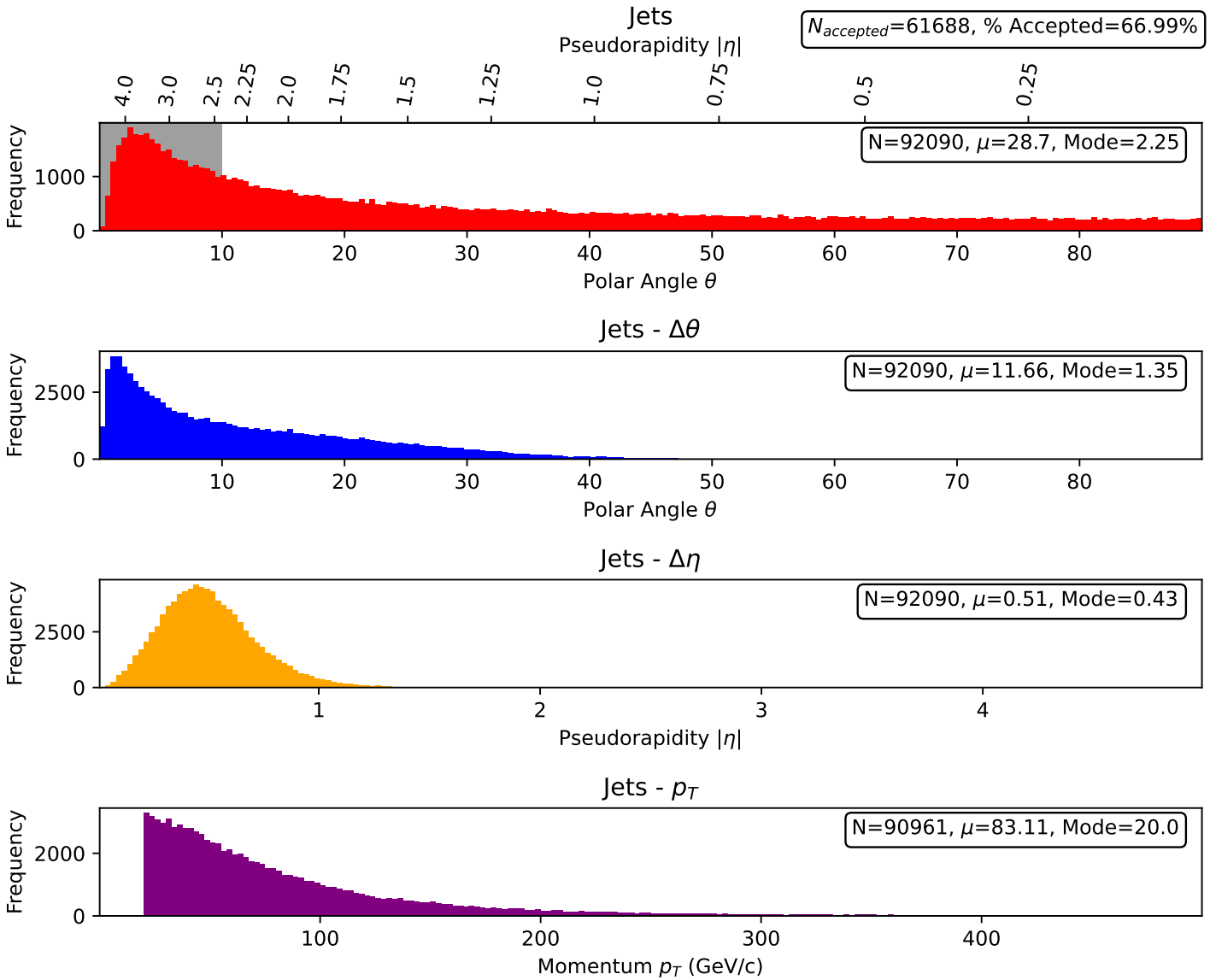


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 15\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

The following are simulated values of $\eta, \Delta\eta, \Delta\theta$, and $p_T$ for reconstructed jets produced from the current design of the muon collider

# Results - Single Higgs

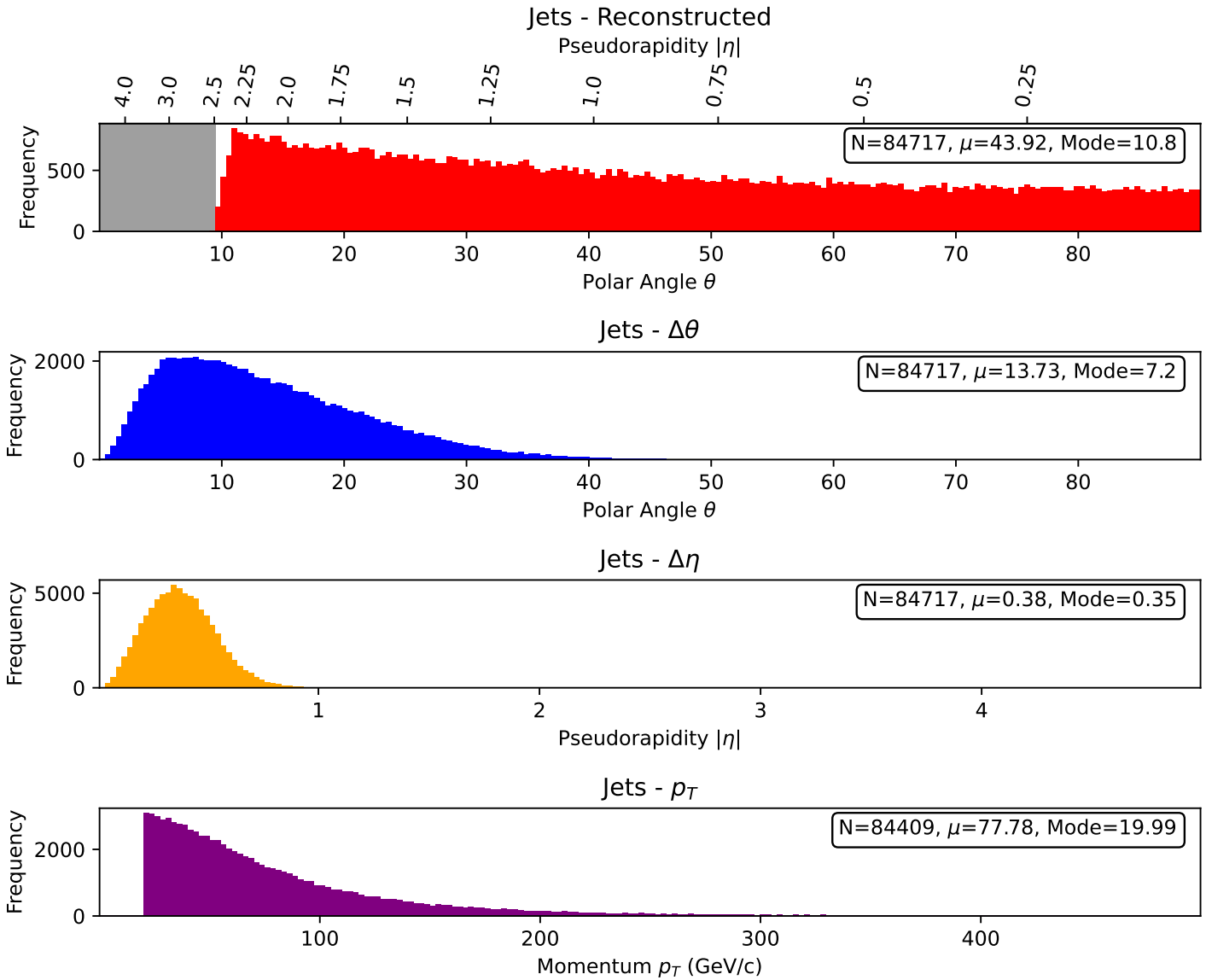


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 3\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

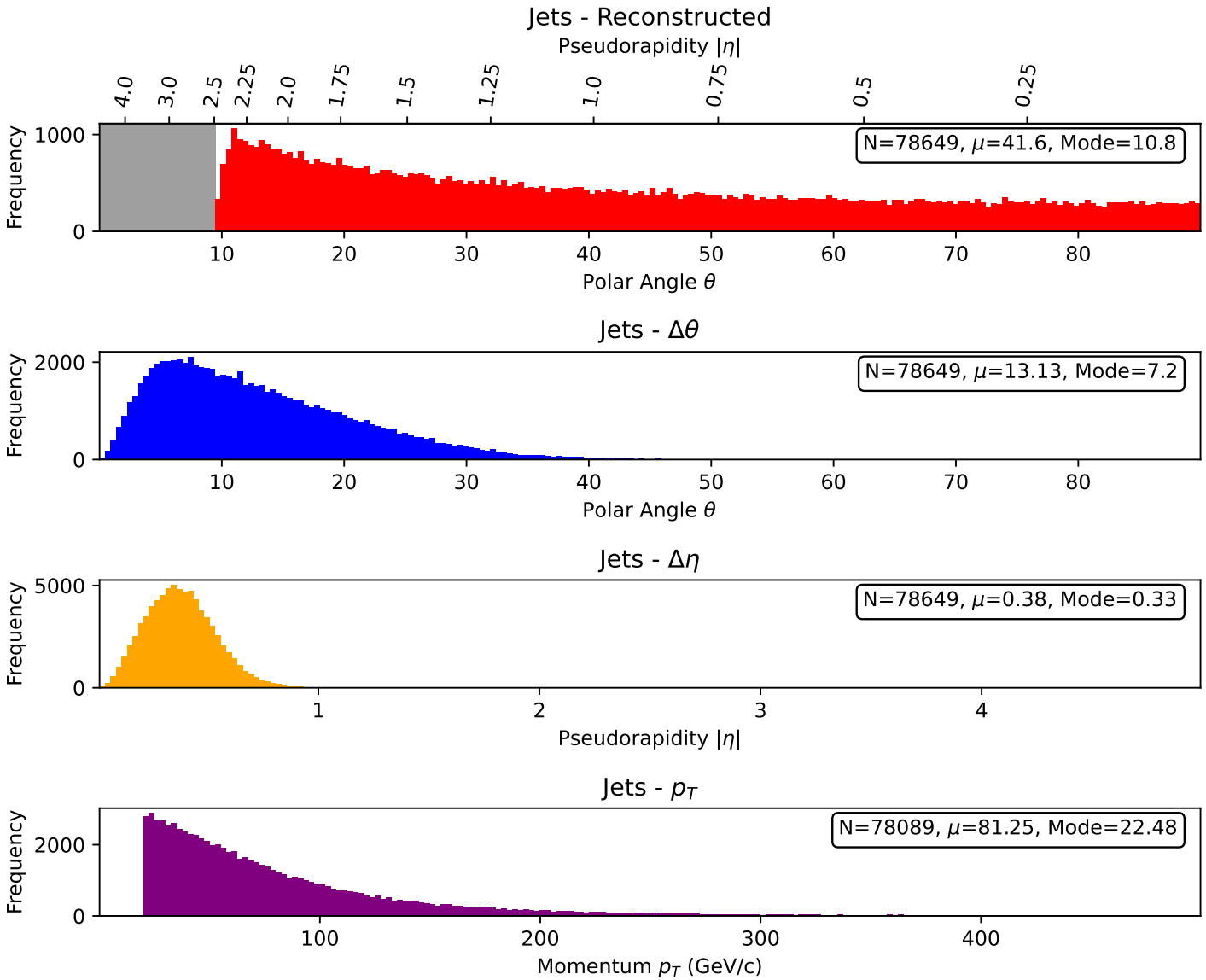


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 5\text{TeV}, N_{\text{events}} = 50,000$

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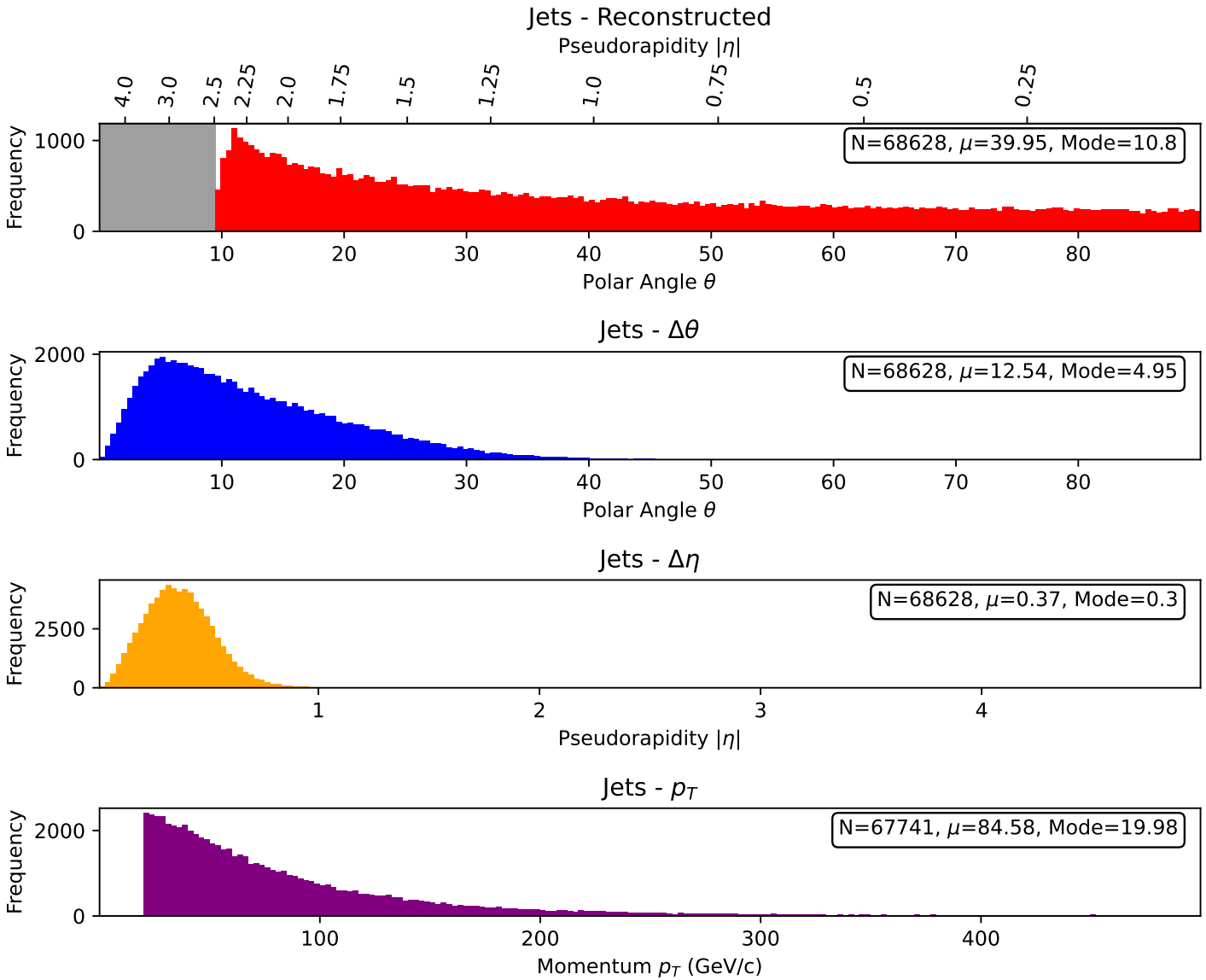


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 10\text{TeV}, N_{\text{events}} = 50,000$

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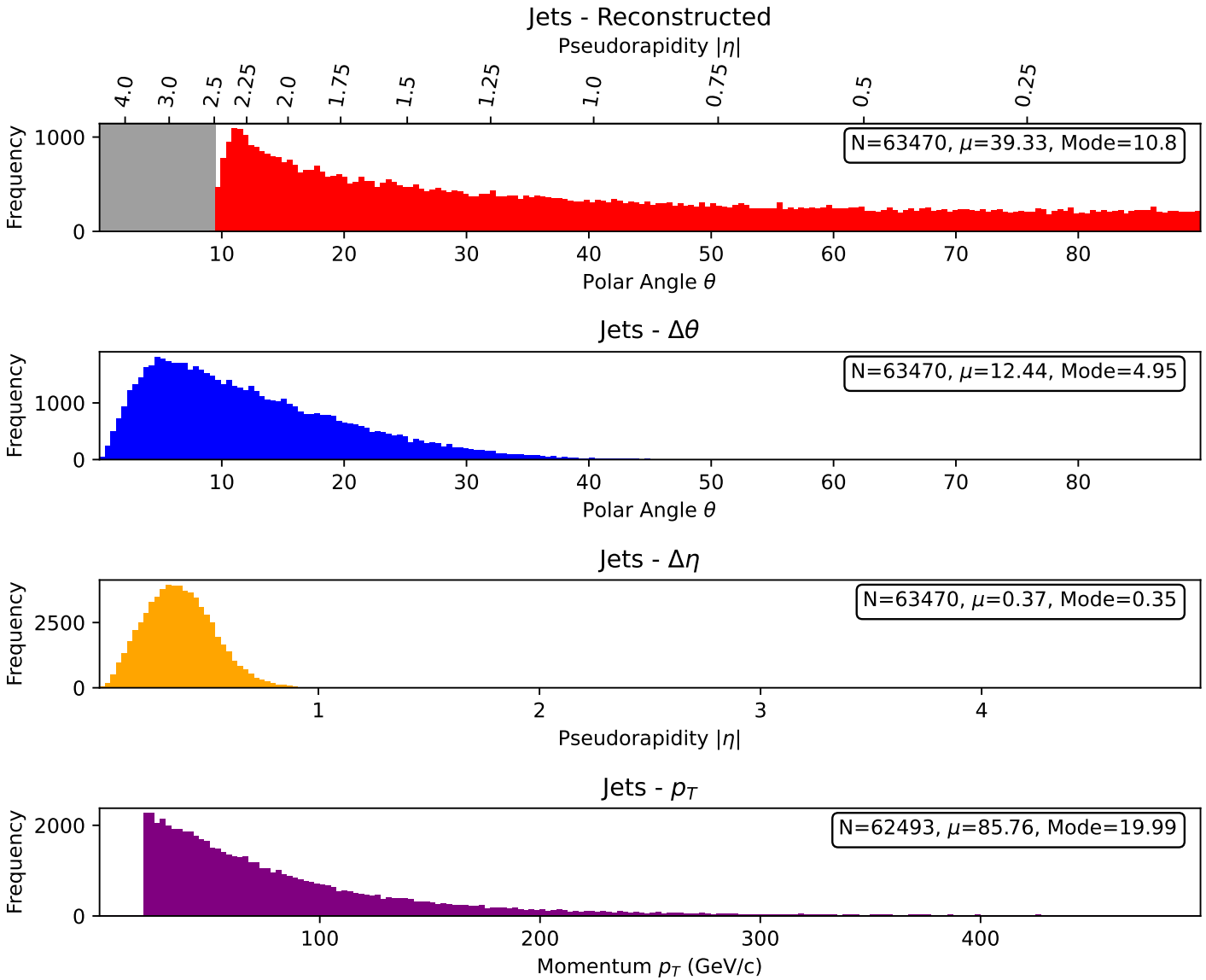



Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 15\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

- The following are predicted values of the Higgs mass from data collected from generated jets which were accepted, and reconstructed jets
- The mass is predicted from the four-vectors of all accepted/reconstructed jets
- The constraint on acceptance contributes to a large peak around $m_H \sim 10\text{GeV}/c^2$ and broadens the peak at $125\text{GeV}/c^2$

# Results - Single Higgs

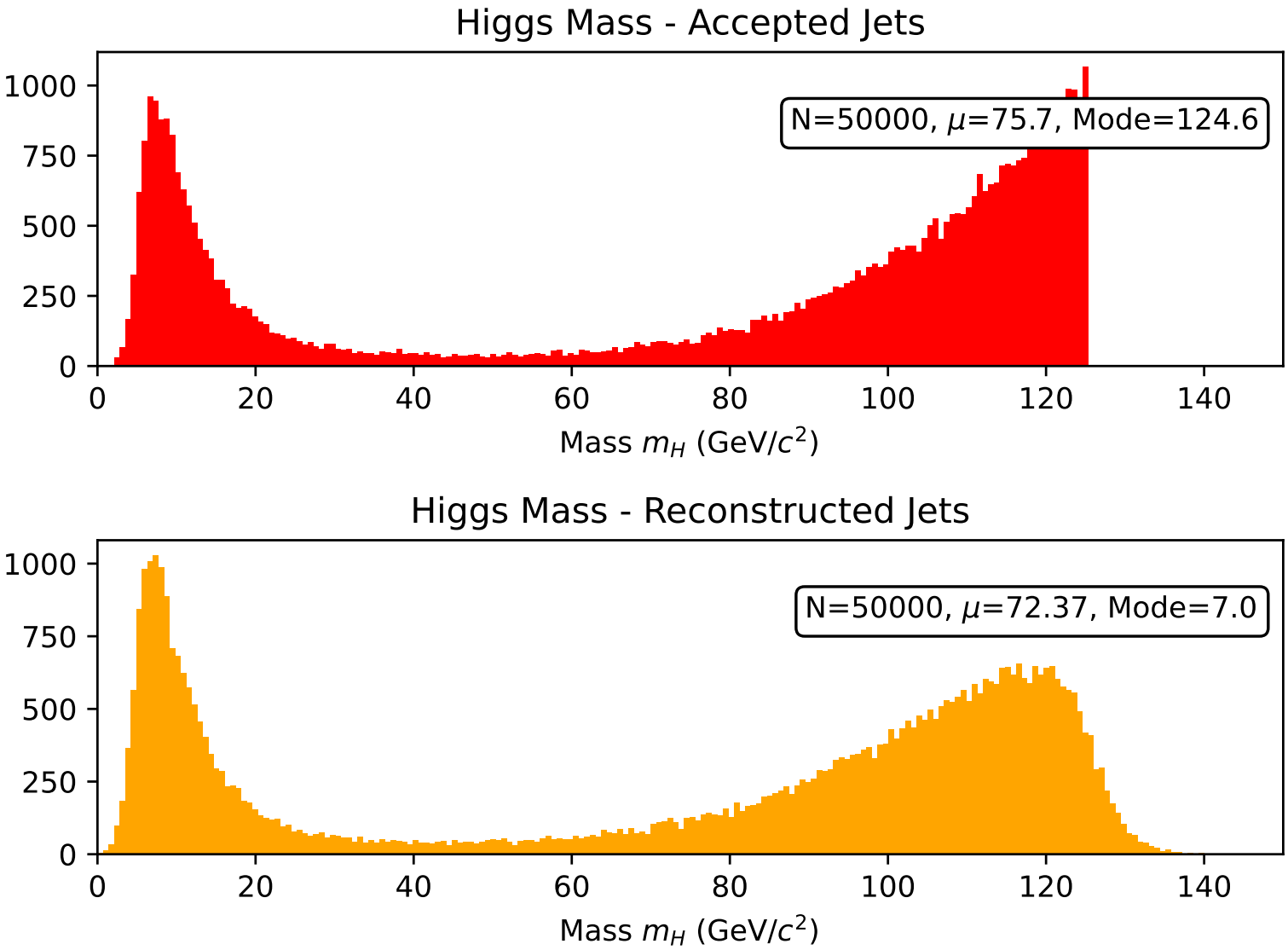
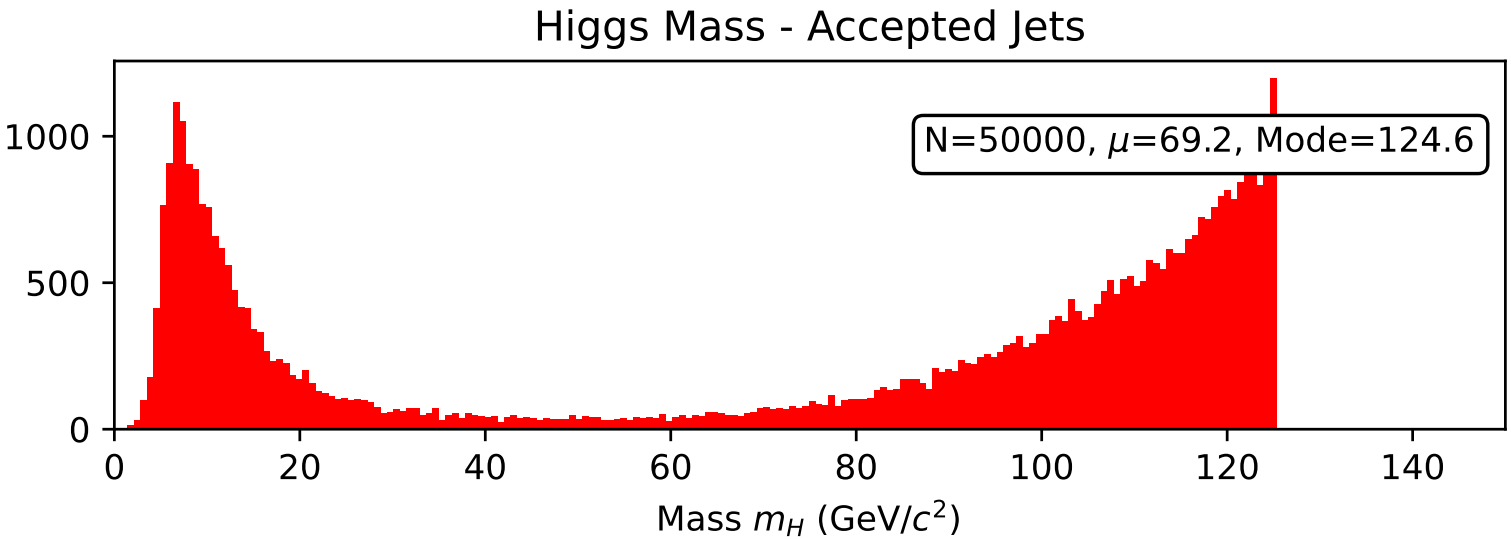



Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 3\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs



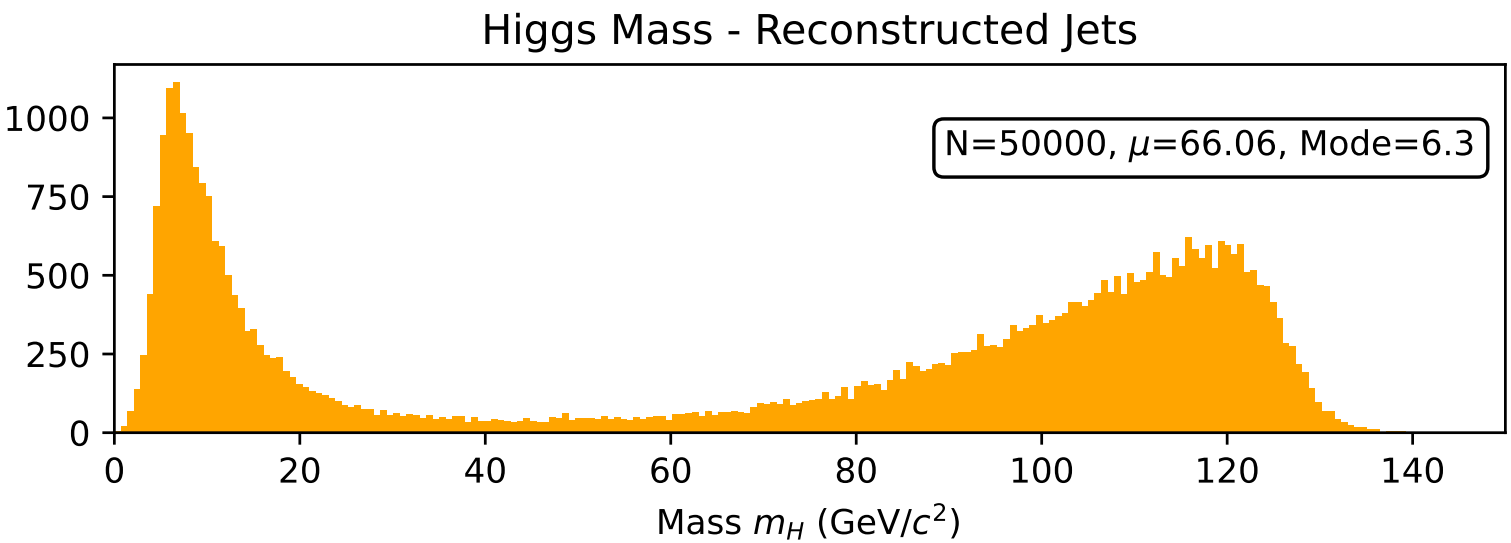




Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} H, H \to b\bar{b}$ at $\sqrt{s} = 5\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

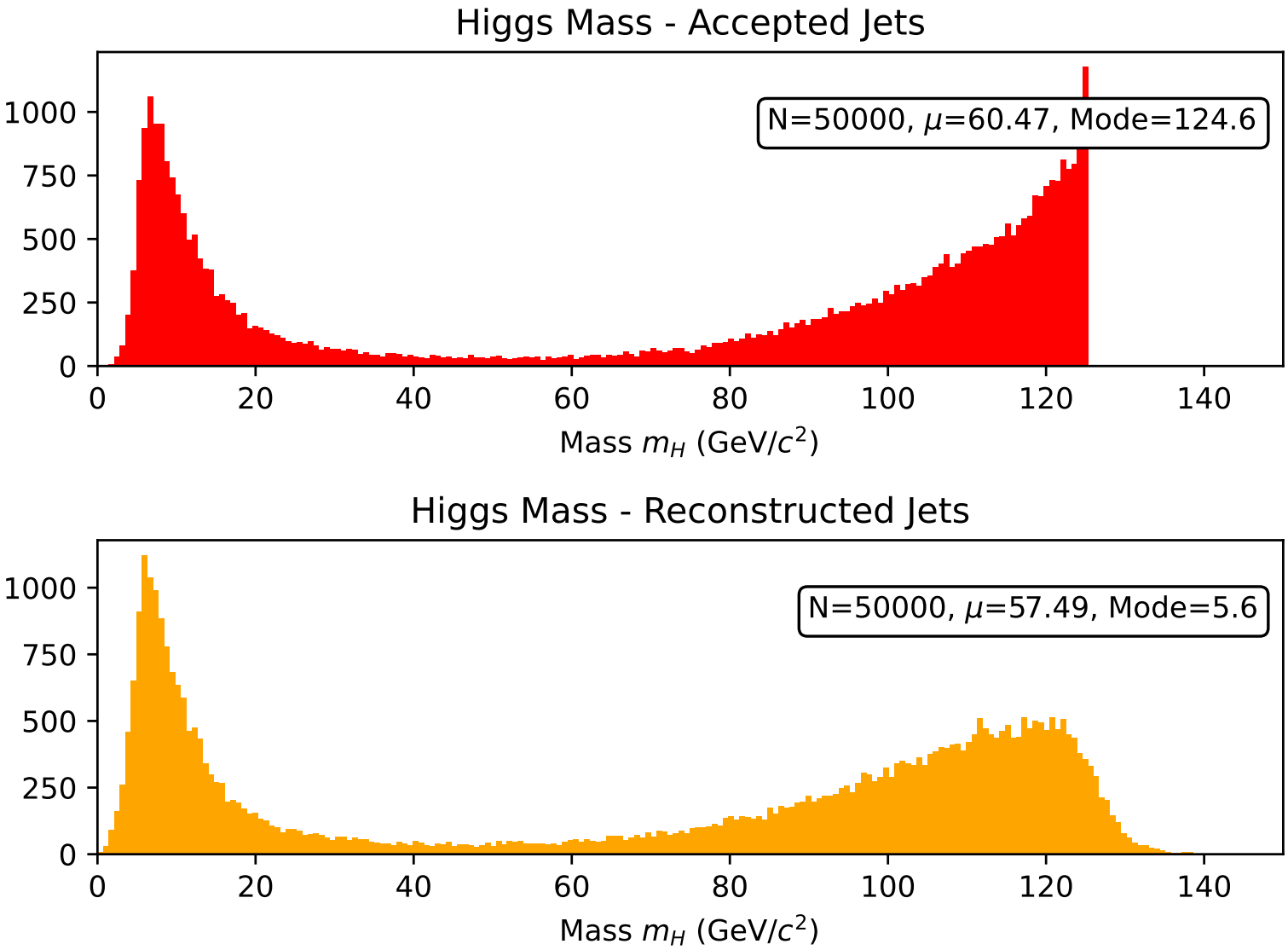



Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu H, H \to b\bar{b}$ at $\sqrt{s} = 10\text{TeV}, N_{\text{events}} = 50,000$

# Results - Single Higgs

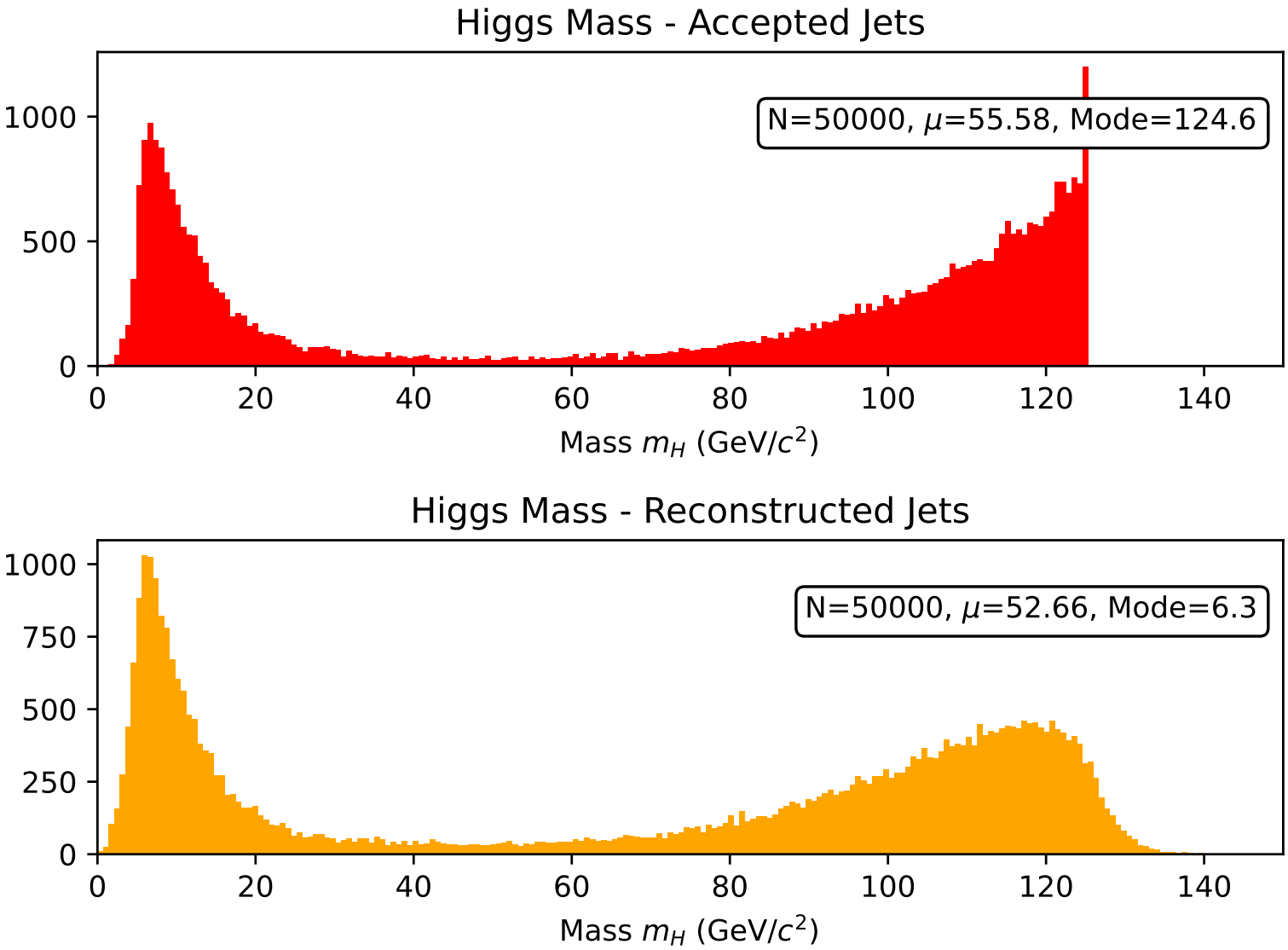
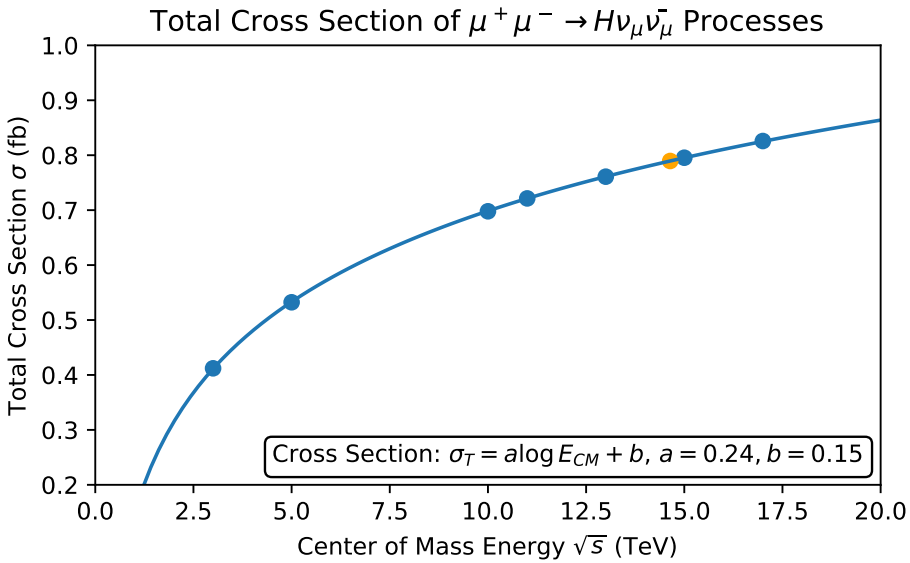


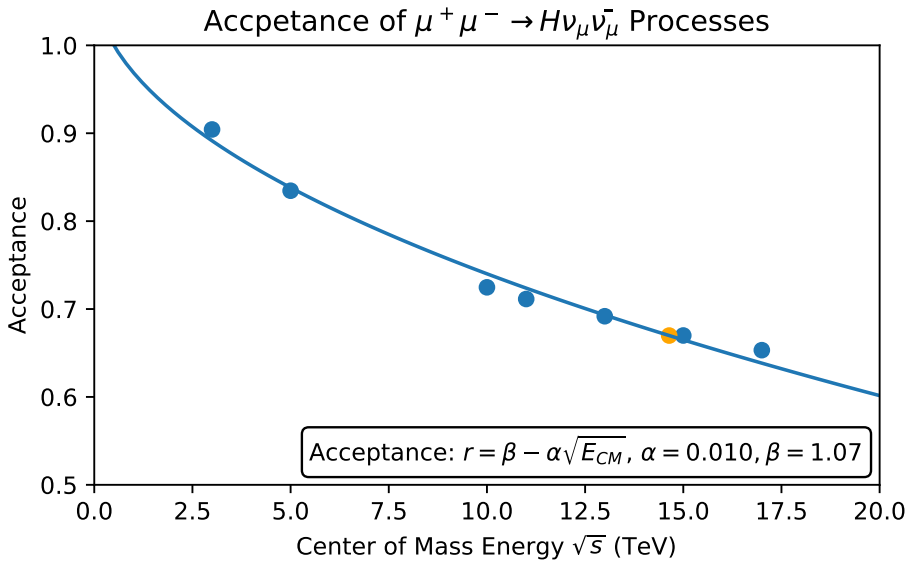

Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu H, H \to b\bar{b}$ at $\sqrt{s} = 15\text{TeV}, N_{\text{events}} = 50,000$

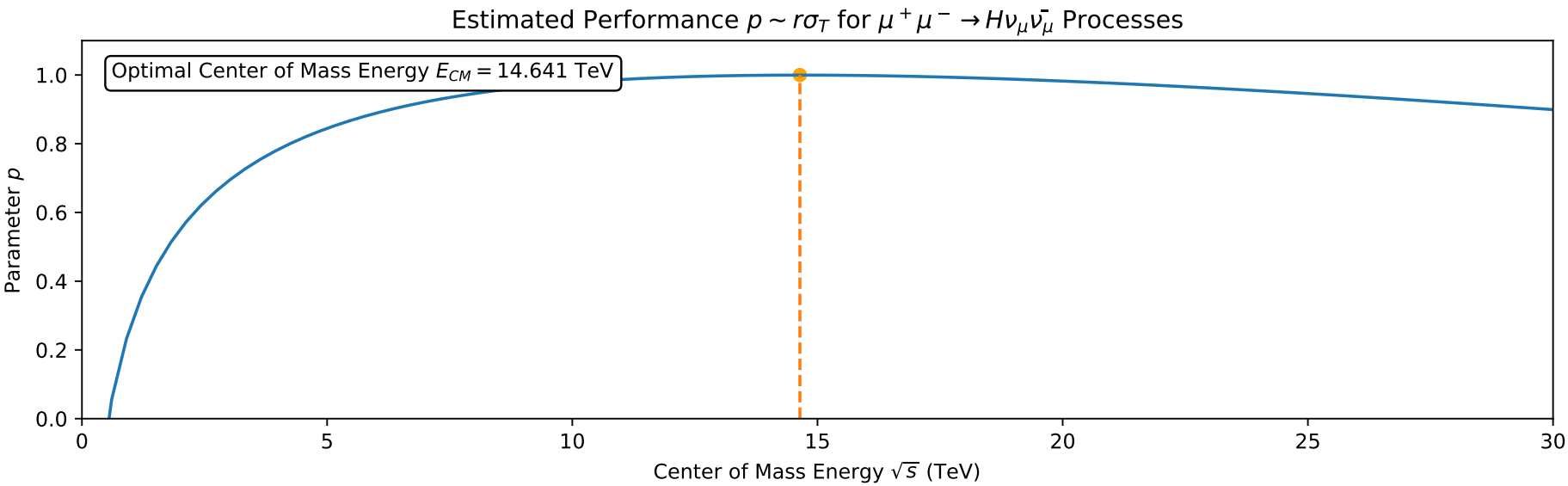
# Results - Di-Higgs

- The following is a plot of cross-sections and acceptances of single-Higgs vector boson fusion at each energy level, including some that were sampled in the past and not included in the presentation
- The acceptance is fit to a power law in $\sqrt{s}$, and the total cross section is fit to $\log(s)$
- Performance, defined as the product of the total cross section and acceptance, peaks around $\sqrt{s} = 15$TeV

# Results - Single Higgs



# Results - Di-Higgs

- Di-Higgs production from vector boson fusion is rarer, but also possible
- Jets produced from di-Higgs events are more forward than jets from single-Higgs events
- The following are simulated values of $|\eta|$ and $p_T$ for the two Higgs and four bottom quark products for center of mass energies $\sqrt{s} = 3, 5, 10\text{TeV}$

# Results - Di-Higgs

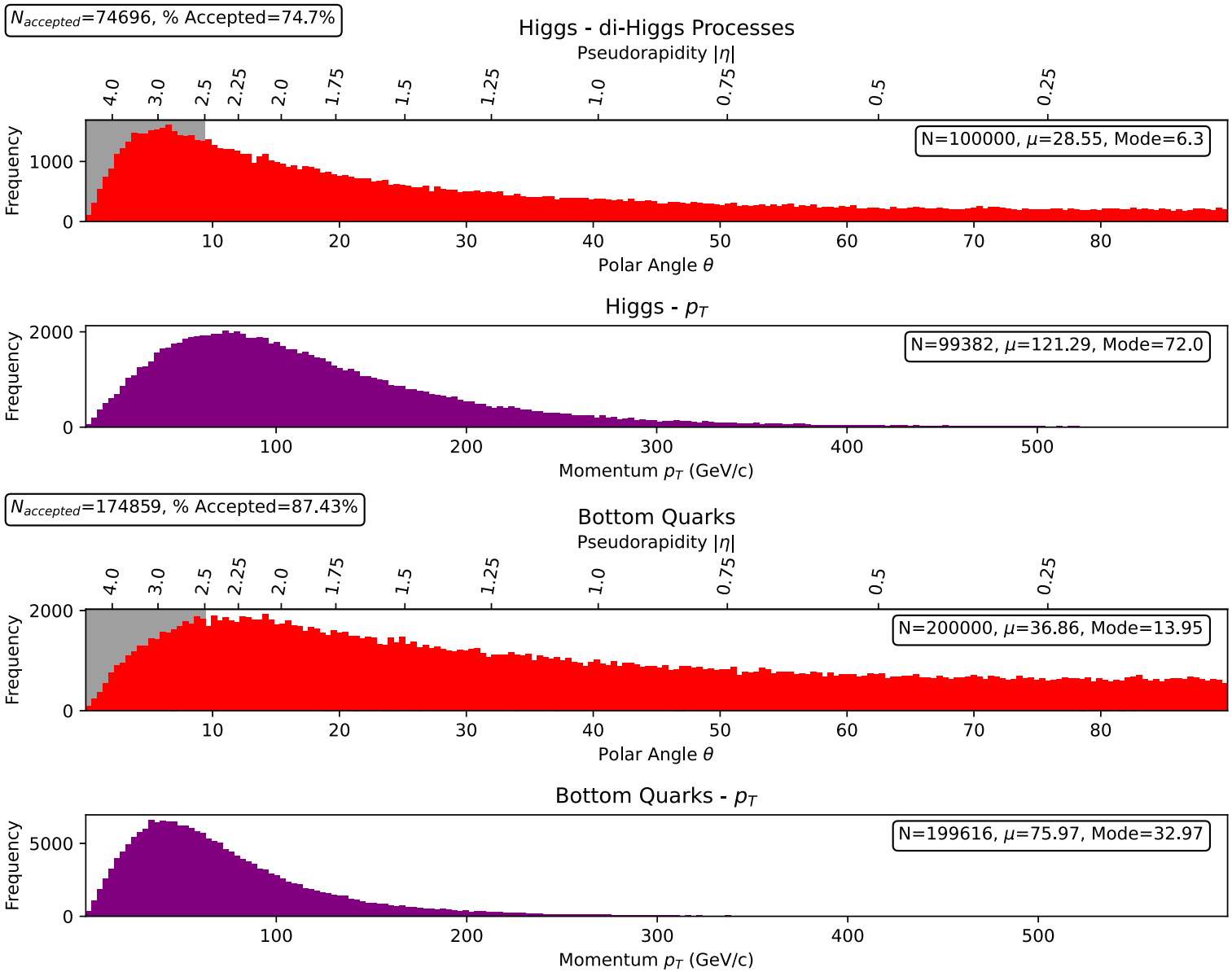



Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu HH, H \to b\bar{b}$ at $\sqrt{s} = 3\text{TeV}, N_{\text{events}} = 50,000$

# Results - Di-Higgs

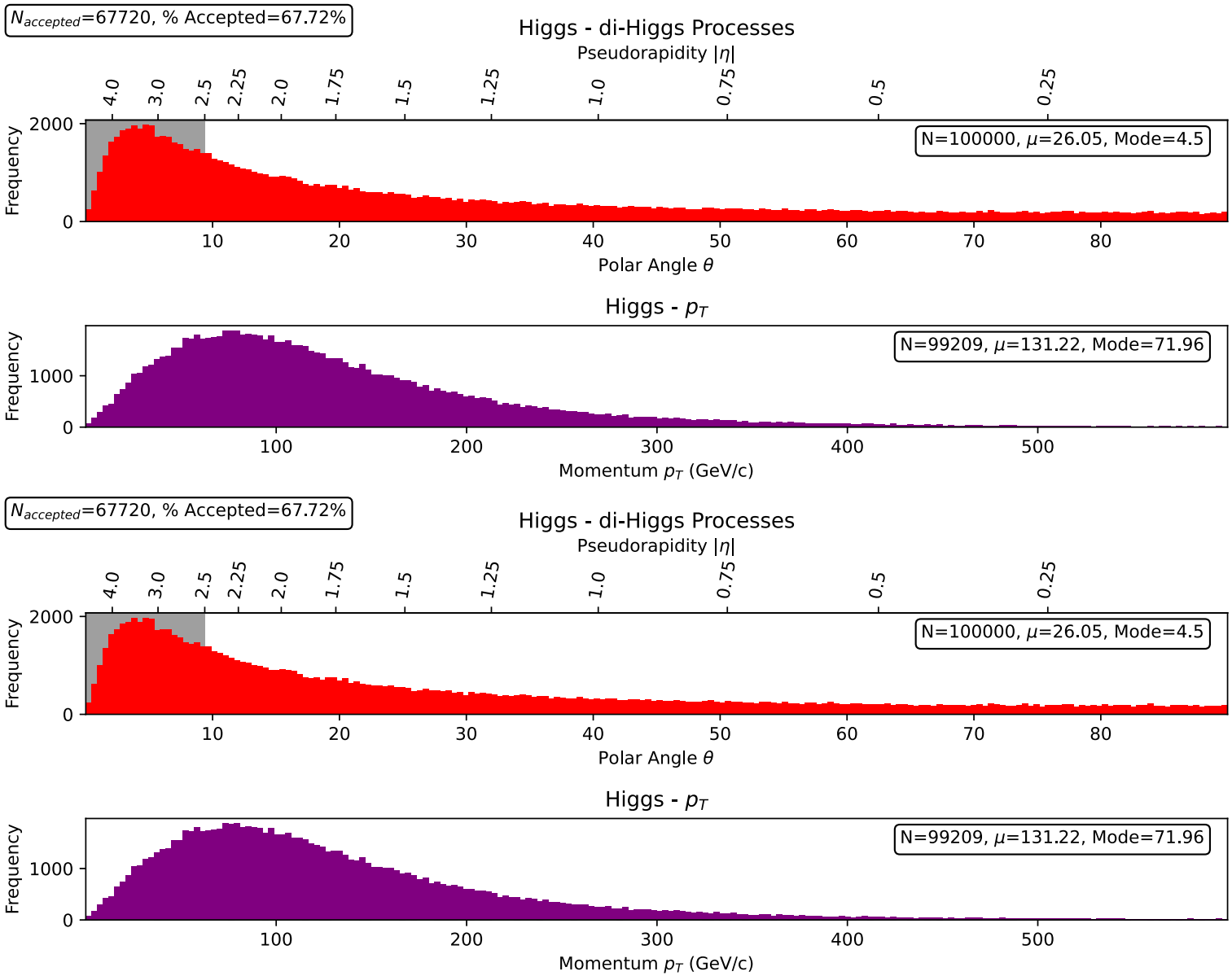



Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu}_\mu HH, H \to b\bar{b}$ at $\sqrt{s} = 5\text{TeV}, N_{\text{events}} = 50,000$

# Results - Di-Higgs

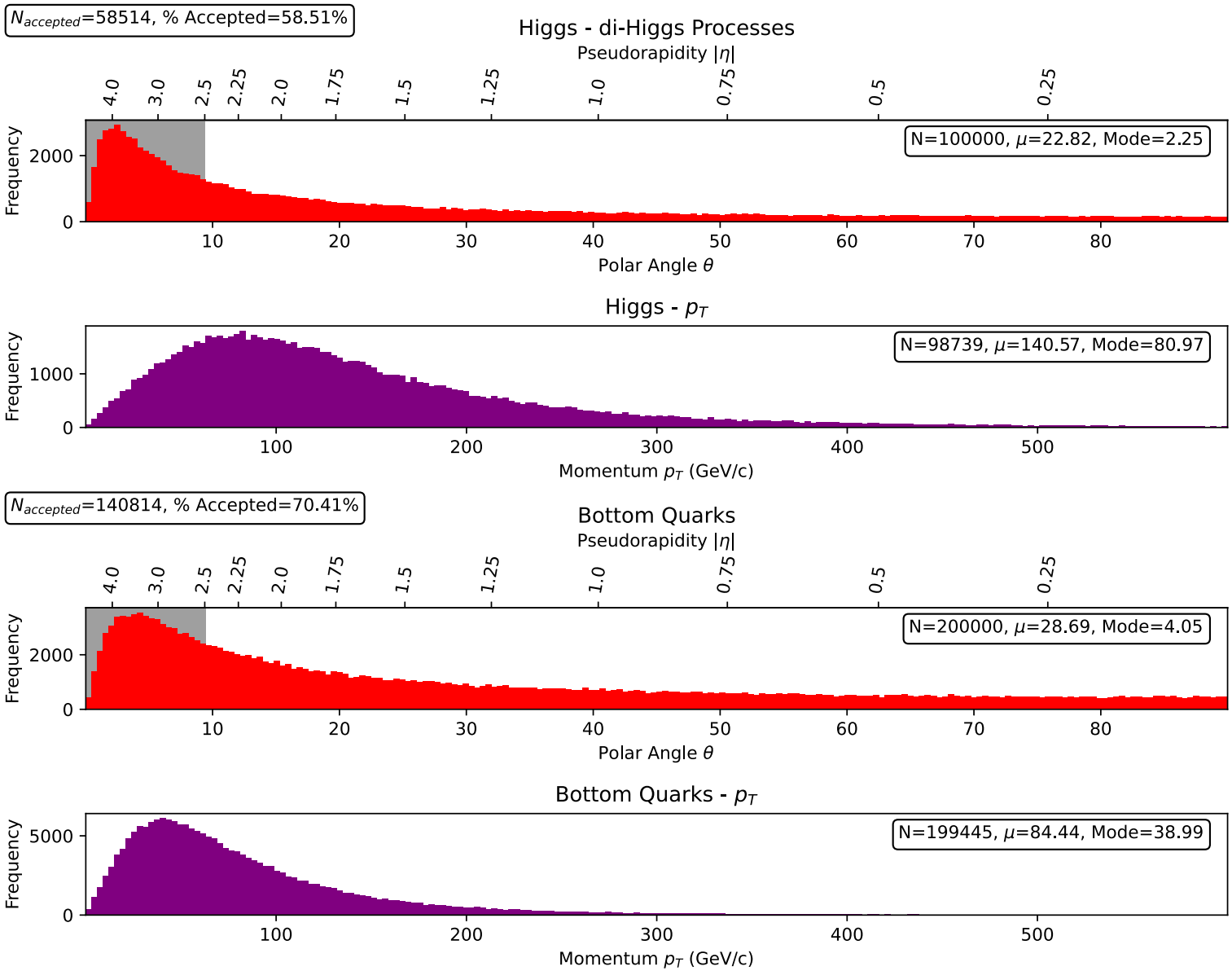
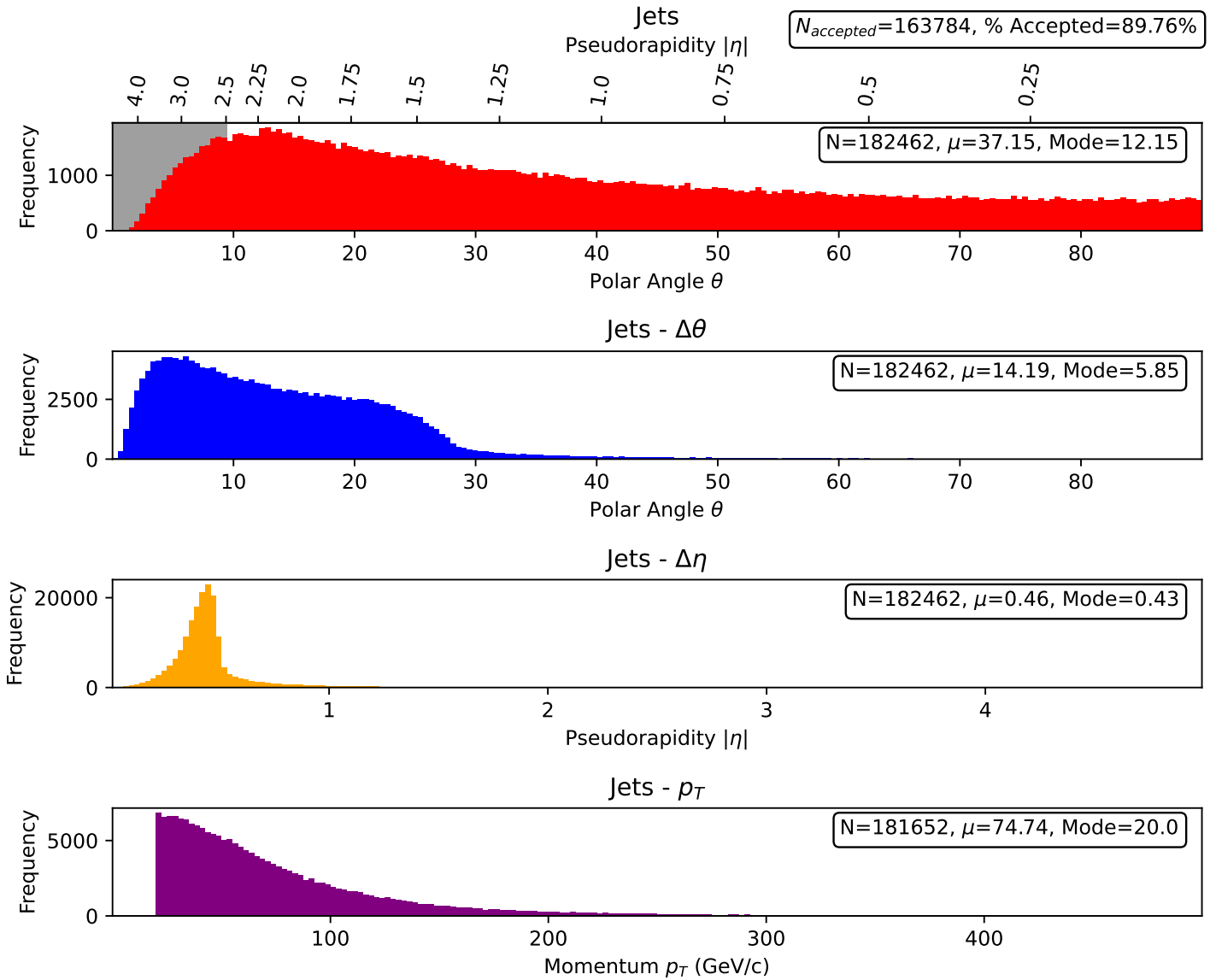



Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} HH, H \to b\bar{b}$ at $\sqrt{s} = 10\text{TeV}, N_{\text{events}} = 50,000$

# Results - Di-Higgs

The following are simulated values of $|\eta|, \Delta\eta, \Delta\theta$, and $p_T$ for jets generated by di-Higgs vector boson fusion

# Results - Di-Higgs

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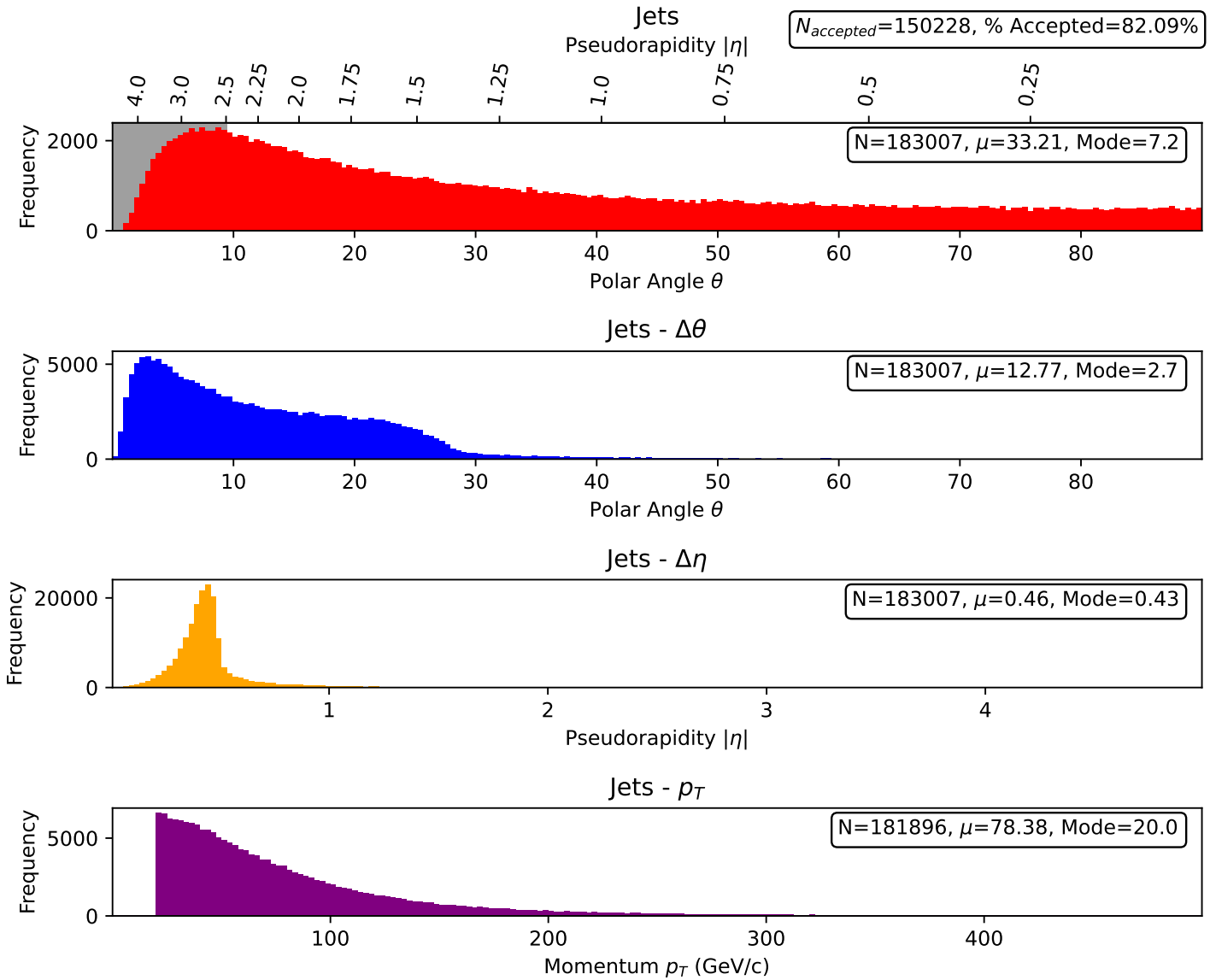


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# Results - Di-Higgs

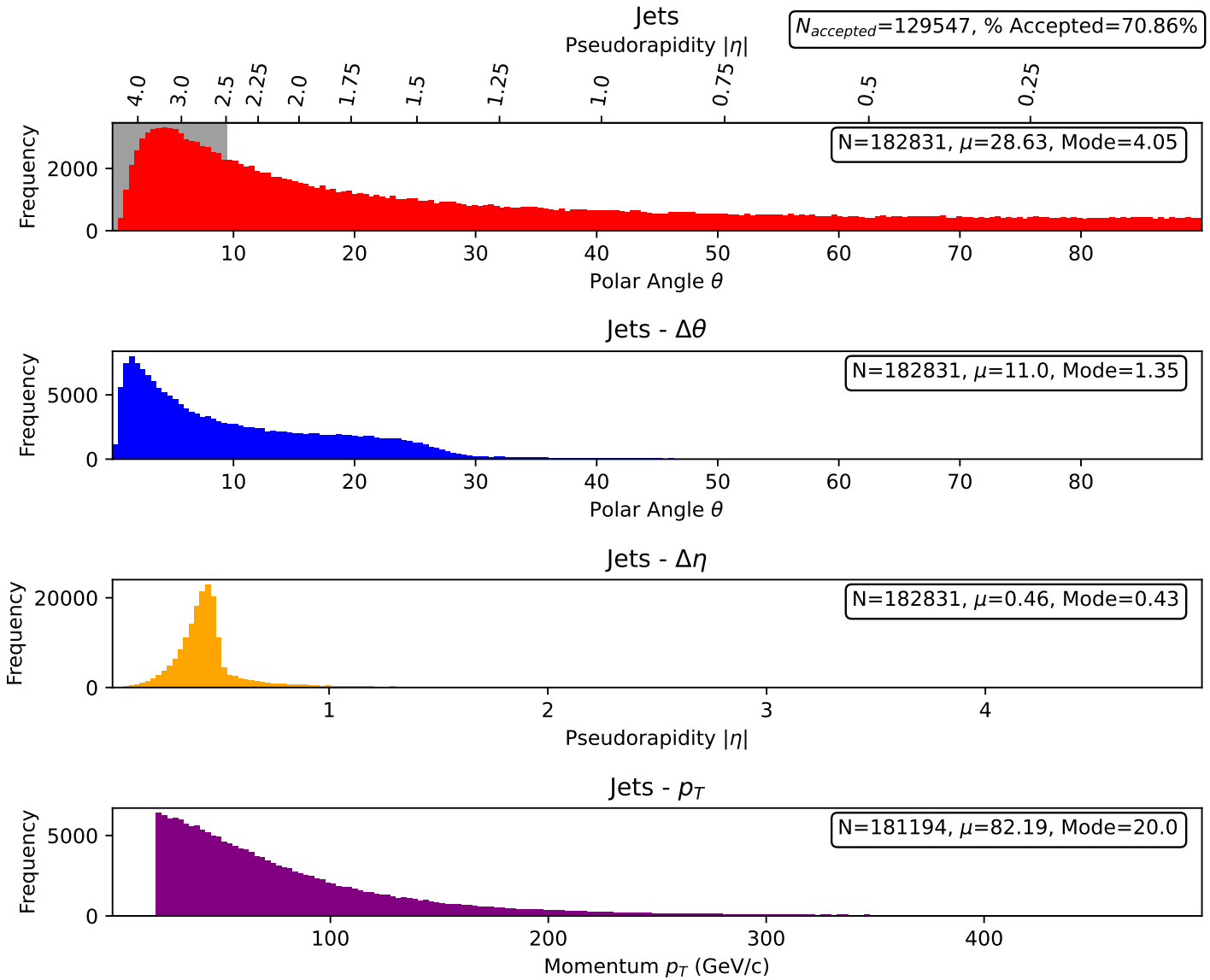


Figure: Process: $\mu^+\mu^- \to \nu_\mu \bar{\nu_\mu} HH, H \to b\bar{b}$ at $\sqrt{s} = 10\text{TeV}, N_{\text{events}} = 50,000$

# Results - Di-Higgs

The following is a plot of cross-sections and acceptances of di-Higgs vector boson fusion at each energy level

Performance, defined as the product of the total cross section and acceptance, peaks around $\sqrt{s} = 16$TeV, slightly higher than single-Higgs vector boson fusion

# Results - Di-Higgs